AN ELECTRONIC BOOK WITH IMPROVED IMAGE QUALITY

The invention relates generally to electronic reading devices such as electronic books and electronic newspapers and, more particularly, to a method and apparatus for improving image quality with such devices by reducing image retention effects.

Recent technological advances have provided "user friendly" electronic reading devices such as e-books that open up many opportunities. For example, electrophoretic displays hold much promise. Such displays have an intrinsic memory behavior and are able to hold an image for a relatively long time without power consumption. Power is consumed only when the display needs to be refreshed or updated with new information. So, the power consumption in such displays is very low, suitable for applications for portable e-reading devices like e-books and e-newspaper. Electrophoresis refers to movement of charged particles in an applied electric field. When electrophoresis occurs in a liquid, the particles move with a velocity determined primarily by the viscous drag experienced by the particles, their charge (either permanent or induced), the dielectric properties of the liquid, and the magnitude of the applied field.

For example, international patent application WO 99/53373, published April 9, 1999, by E Ink Corporation, Cambridge, Massachusetts, US, and entitled Full Color Reflective Display With Multichromatic Sub–Pixels, describes such a display device. WO 99/53373 discusses an electronic ink display having two substrates. One is transparent, and the other is provided with electrodes arranged in rows and columns. A display element or pixel is associated with an intersection of a row electrode and column electrode. The display element is coupled to the column electrode using a thin film transistor (TFT), the gate of which is coupled to the row electrode. This arrangement of display elements, TFT transistors, and row and column electrodes together forms an active matrix. Furthermore, the display element comprises a pixel electrode. A row driver selects a row of display elements, and a column driver supplies a data signal to the selected row of display elements via the column electrodes and the TFT transistors. The data signals correspond to graphic data to be displayed, such as text or figures.

The electronic ink is provided between the pixel electrode and a common electrode on the transparent substrate. The electronic ink comprises multiple

microcapsules of about 10 to 50 microns in diameter. In one approach, each microcapsule has positively charged white particles and negatively charged black particles suspended in a liquid carrier medium or fluid. When a positive voltage is applied to the pixel electrode, the white particles move to a side of the microcapsule directed to the transparent substrate and a viewer will see a white display element. At the same time, the black particles move to the pixel electrode at the opposite side of the microcapsule where they are hidden from the viewer. By applying a negative voltage to the pixel electrode, the black particles move to the common electrode at the side of the microcapsule directed to the transparent substrate and the display element appears dark to the viewer. At the same time, the white particles move to the pixel electrode at the opposite side of the microcapsule where they are hidden from the viewer. When the voltage is removed, the display device remains in the acquired state and thus exhibits a bi-stable character. In another approach, particles are provided in a dyed liquid. For example, black particles may be provided in a white liquid, or white particles may be provided in a black liquid. Or, other colored particles may be provided in different colored liquids, e.g., white particles in green liquid.

Other fluids such as air may also be used in the medium in which the charged black and white particles move around in an electric field (e.g., Bridgestone SID2003 – Symposium on Information Displays. May 18-23, 2003, - digest 20.3). Colored particles may also be used.

To form an electronic display, the electronic ink may be printed onto a sheet of plastic film that is laminated to a layer of circuitry. The circuitry forms a pattern of pixels that can then be controlled by a display driver. Since the microcapsules are suspended in a liquid carrier medium, they can be printed using existing screen-printing processes onto virtually any surface, including glass, plastic, fabric and even paper. Moreover, the use of flexible sheets allows the design of electronic reading devices that approximate the appearance of a conventional book.

However, one difficulty with such electronic reading devices is that the image quality is reduced due to image retention effects. In particular, due to the strong memory effect of E-ink type displays, a previous image may not be fully erased when the next image is displayed, in particular when the pixels are repeatedly switched, leading to an

integration of the image retention on the display. The memory effect of a pixel is mainly localized to each pixel but can sometimes depend on surrounding pixels. To avoid an unacceptable build up of image retention effects over time, a reset is periodically performed by switching the whole display between full black and full white states, e.g., at least three times. A reset pulse is used having a duration, e.g., up to 500 msec., that is sufficient to move the particles to extreme optic states, e.g., black or white. The reset is inconvenient for the user because it usually lasts between three to five seconds and is clearly visible. It would therefore be desirable to reduce image retention effects to reduce the frequency with which such resets are needed.

The present invention addresses the above and other issues.

In one aspect of the invention, a method is provided for displaying information on an electronic reading device having a display region with pixels arranged in a plurality of rows and columns. Each pixel may comprise switching electronics such as thin film transistors (TFTs), diodes or metal-insulator-metal (MIM) devices, for instance. The method includes displaying a first page on the display region starting at a first location, such as a row or column, of the display region, and, in response to a next page command, displaying a second page on the display region in place of the first page starting at a second location, such as row or column, of the display region that is different than the first location. In response to subsequent next page commands, subsequent pages are displayed on the display region, in turn, starting at varying locations of the display region. Vertical row shifting and horizontal column shifting may be employed separately or in combination.

A related electronic reading device and computer program product are also provided.

In the drawings:

Fig. 1 shows diagramatically a front view of an embodiment of a portion of a display screen of an electronic reading device;

Fig. 2 shows diagramatically a cross-sectional view along 2-2 in Fig. 1;

Fig. 3 shows diagramatically an overview of an electronic reading device;

Fig. 4 shows diagramatically two display screens with respective display regions;

Fig. 5 shows diagramatically a display screen displaying a first page with row shifting;

Fig. 6 shows diagramatically a display screen displaying a second page with row shifting;

Fig. 7 shows diagramatically a display screen displaying a third page with row shifting;

Fig. 8 shows diagramatically a display screen displaying a first page with column shifting;

Fig. 9 shows diagramatically a display screen displaying a second page with column shifting;

Fig. 10 shows diagramatically a display screen displaying a third page with column shifting;

Fig. 11 shows diagramatically a display screen displaying a first page with row and column shifting;

Fig. 12 shows diagramatically a display screen displaying a second page with row and column shifting; and

Fig. 13 shows diagramatically a display screen displaying a third page with row and column shifting.

In all the Figures, corresponding parts are referenced by the same reference numerals.

Figures 1 and 2 show the embodiment of a portion of a display panel 1 of an electronic reading device having a first substrate 8, a second opposed substrate 9 and a plurality of picture elements 2. The picture elements 2 may be arranged along substantially straight lines in a two-dimensional structure. The picture elements 2 are shown spaced apart from one another for clarity, but in practice, the picture elements 2 are very close to one another so as to form a continuous image. Moreover, only a portion of a full display screen is shown. Other arrangements of the picture elements are possible, such as a honeycomb arrangement. An electrophoretic medium 5 having charged particles 6 is present between the substrates 8 and 9. A first electrode 3 and second electrode 4 are associated with each picture element 2. The electrodes 3 and 4 are able to receive a potential difference. In Fig. 2, for each picture element 2, the first

substrate has a first electrode 3 and the second substrate 9 has a second electrode 4. The charged particles 6 are able to occupy positions near either of the electrodes 3 and 4 or intermediate to them. Each picture element 2 has an appearance determined by the position of the charged particles 6 between the electrodes 3 and 4. Electrophoretic media 5 are known per se, e.g., from U.S. patents 5,961,804, 6,120,839, and 6,130,774 and can be obtained, for instance, from E Ink Corporation.

As an example, the electrophoretic medium 5 may contain negatively charged black particles 6 in a white fluid. When the charged particles 6 are near the first electrode 3 due to a potential difference of, e.g., +15 Volts, the appearance of the picture elements 2 is white. When the charged particles 6 are near the second electrode 4 due to a potential difference of opposite polarity, e.g., -15 Volts, the appearance of the picture elements 2 is black. When the charged particles 6 are between the electrodes 3 and 4, the picture element has an intermediate appearance such as a grey level between black and white. A drive control 100 controls the potential difference of each picture element 2 to create desired images or text in a full display screen. The full display screen is made up of numerous picture elements that correspond to pixels in a display.

Fig. 3 shows diagramatically an overview of an electronic reading device. The electronic reading device 300 includes the control 100, including an addressing circuit 105. The control 100 controls the one or more display screens 310, such as electrophoretic screens, to cause desired text or images to be displayed. For example, the control 100 may provide voltage waveforms to the different pixels in the display screen 310. The addressing circuit provides information for addressing specific pixels, such as row and column, to cause the desired image or text to be displayed. As described further below, the control 100 causes successive pages to be displayed starting on different rows and/or columns. The image or text data may be stored in a memory 120. One example is the Philips Electronics small form factor optical (SFFO) disk system. The control 100 may be responsive to a user-activated software or hardware button 320 that initiates a user command such as a next page command or previous page command.

The control 100 may be part of a computer that executes any type of computer code devices, such as software, firmware, micro code or the like, to achieve the functionality described herein. Accordingly, a computer program product comprising

such computer code devices may be provided in a manner apparent to those skilled in the art. The control 100 may have logic for periodically providing a forced reset of a display region of an electronic book, e.g., after every x pages are displayed, after every y minutes, e.g., ten minutes, when the electronic reading device is first turned on, and/or when the brightness deviation is larger than a value such as 3% reflection. For automatic resets, an acceptable frequency can be determined empirically based on the lowest frequency that results in acceptable image quality. Also, the reset can be initiated manually by the user via a function button or other interface device, e.g., when the user starts to read the electronic reading device, or when the image quality drops to an unacceptable level. The required reset frequency is reduced with the invention, e.g., by 80% or more.

The invention may be used with any type of electronic reading device. Fig. 4 illustrates one possible example of an electronic reading device 400 having two separate display screens. Specifically, a first display region 442 is provided on a first screen 440, and a second display region 452 is provided on a second screen 450. The screens 440 and 450 may be connected by a binding 445 that allows the screens to be folded flat against each other, or opened up and laid flat on a surface. This arrangement is desirable since it closely replicates the experience of reading a conventional book.

Various user interface devices may be provided to allow the user to initiate page forward, page backward commands and the like. For example, the first region 442 may include on-screen buttons 424 that can be activated using a mouse or other pointing device, a touch activation, PDA pen, or other known technique, to navigate among the pages of the electronic reading device. In addition to page forward and page backward commands, a capability may be provided to scroll up or down in the same page. Hardware buttons 422 may be provided alternatively, or additionally, to allow the user to provide page forward and page backward commands. The second region 452 may also include on-screen buttons 414 and/or hardware buttons 412. Note that the frame 405 around the first and second display regions 442, 452 is not required as the display regions may be frameless. Other interfaces, such as a voice command interface, may be used as well. Note that the buttons 412, 414; 422, 424 are not required for both display regions. That is, a single set of page forward and page backward buttons may be provided. Or, a

single button or other device, such as a rocker switch, may be actuated to provide both page forward and page backward commands. A function button or other interface device can also be provided to allow the user to manually initiate a reset.

In other possible designs, an electronic book has a single display screen with a single display region that displays one page at a time. Or, a single display screen may be partitioned into two or more display regions arranged, e.g., horizontally or vertically. In any case, the invention can be used with each display region to reduce memory retention effects.

Furthermore, when multiple display regions are used, successive pages can be displayed in any desired order. For example, in Fig. 4, a first page can be displayed on the display region 442, while a second page is displayed on the display region 452. When the user requests to view the next page, a third page may be displayed in the first display region 442 in place of the first page while the second page remains displayed in the second display region 452. Similarly, a fourth page may be displayed in the second display region 452, and so forth. In another approach, when the user requests to view the next page, both display regions are updated so that the third page is displayed in the first display region 442 in place of the first page, and the fourth page is displayed in the second display region 452 in place of the second page. When a single display region is used, a first page may be displayed, then a second page overwrites the first page, and so forth, when the user enters a next page command. The process can work in reverse for page back commands. Moreover, the process is equally applicable to languages in which text is read from right to left, such as Hebrew, as well as to languages such as Chinese in which text is read column-wise rather than row-wise.

Additionally, note that the entire page need not be displayed on the display region. A portion of the page may be displayed and a scrolling capability provided to allow the user to scroll up, down, left or right to read other portions of the page. A magnification and reduction capability may be provided to allow the user to change the size of the text or images. This may be desirable for users with reduced vision, for example.

Fig. 5 shows diagramatically a display screen with rows used to display a first page. The display screen or region 520 is shown having a number of pixels 2 arranged in

rows and columns. Only a few pixels are shown as an example, e.g., twelve pixels in width by sixteen pixels in height. The region 520 may therefore be considered to form only a portion of a complete image or page. In practice, thousands or millions of pixels are used to provide a continuous, high-quality image. As explained previously, a desired image/text can be displayed on the display region 520 by controlling each pixel according to its specific row and column address. In particular, a row driver 510 and column driver (source driver) 500 provide signals to each pixel to display a desired image, such as a page of text to be read by a user. In accordance with the invention, when a new page is to be displayed in the display region 520, the new page is displayed starting at a different location, such as a different row, than the previous page. For example, in Fig. 5, a first page is displayed using the shaded pixels 530, which form a subset of all pixels in the display region 520. In particular, the first page is displayed starting on the first row of the display region 520 and extending through the fourteenth row. The fifteenth and sixteen rows are not used for displaying the first page.

Fig. 6 illustrates a second page displayed on the second through fifteenth rows of the display region 520, as shown by the shaded pixels 630. Here, the display of the second page has started on the second row of the display region 520. Fig. 7 illustrates a third page displayed on the third through sixteenth rows of the display region 520. Thus, the row on which the display of each page starts is varied from page to page. In one approach, the rows on which the display of the pages starts are determined according to a varying offset from a reference row of the display region. For example, the reference row can be the first row of the display region or any other designated row. Moreover, the offset can vary between a minimum value and a maximum value. For example, for the first page in Fig. 5, the offset from the first row is the minimum value of zero since there is no offset. For the second page in Fig. 6, the offset from the first row is one row, and for the third page in Fig. 7, the offset from the first row is two rows. If the bottom row is chosen as the reference row, the offsets for the first, second and third pages are fifteen, fourteen and thirteen rows, respectively.

Many different variations of this idea are possible. For example, the starting row can be changed for every page that is displayed, or every other page, or every third page, etc., although changing the starting row for every page is believed to provide the greatest

reduction of image retention effects. Each page may be considered to be whatever image/text is displayed on the display screen. Moreover, the starting row can be changed by one or more rows per page. Additionally, it is not required to increment the starting row by the same amount for each page. Furthermore, the offset from the reference row can be varied so that it increases from the minimum value until the maximum value is reached, at which time the offset is reset to the minimum value, e.g., in a cycle. This could be implemented with successive offsets of 0, 1, 2, 3, 0, 1, 2, 3, ... rows, for instance. In another approach, the offset is varied so that it increases from the minimum value until the maximum value is reached, at which time it decreases until the minimum value is reached. This could be implemented with successive offsets of 0, 1, 2, 3, 2, 1, 0, 1, 2, 3, ... rows, for instance. The maximum offset can be any number of rows. For example, when pages of text are displayed, the maximum offset can be based on the height of the space between the lines of text. This ensures that the blank space between the lines that would not otherwise be used is in fact used to display text, thereby avoiding a build up of image retention effects in specific locations on a display. The maximum offset should not be so large that the shifted pages are inconvenient or distracting to the user. For example, the maximum offset may be limited to the height of one line of text added to the height of the space between lines of text.

In addition to the row shifting technique discussed, an analogous column shifting technique may be used by itself or in combination with row shifting. For example, Fig. 8 shows diagramatically the display screen 520 displaying a first page with column shifting. Here, the first page is displayed using the shaded pixels 830, which form a subset of all pixels in the display region 520. The first page is displayed starting at the location of the first column of the display region 520 and extending through the tenth column. The eleventh and twelfth columns are not used for displaying the first page.

Fig. 9 illustrates a second page displayed on the second through eleventh columns of the display region 520, as shown by the shaded pixels 930. Here, the display of the second page has started at the location of the second column of the display region 520. Fig. 10 illustrates a third page displayed on the third through twelfth columns of the display region 520 as shown by the shaded pixels 1030. Thus, the column on which the display of each page starts is varied from page to page. In one approach, the columns on

which the display of the pages starts are determined according to a varying offset from a reference column of the display region. For example, the reference column can be the first column of the display region or any other designated column. Moreover, the offset can vary between a minimum value and a maximum value in a manner that is analogous to the row shifting technique discussed above.

In other variations, the starting column can be changed for every page that is displayed, or every other page, or every third page, etc., although changing the starting column for every page is believed to provide the greatest reduction of image retention effects. Moreover, the starting column can be changed by one or more columns per page. Additionally, it is not required to increment the starting column by the same amount for each page. Furthermore, the offset from the reference column can be varied so that it increases from the minimum value until the maximum value is reached, at which time the offset is reset to the minimum value, e.g., in a cycle. In another approach, the offset is varied so that it increases from the minimum value until the maximum value is reached, at which time it decreases until the minimum value is reached. The maximum offset can be any number of columns. The maximum offset should not be so large that the shifted pages are inconvenient or distracting to the user. For example, the maximum offset may be limited to the width of one character of text.

Row shifting and column shifting may be also be employed in combination. Figures 11, 12 and 13 show diagramatically a display screen displaying first, second and third pages, respectively, with row and column shifting. The first page is displayed using the shaded pixels 1130, while the second page is displayed using the shaded pixels 1230, and the third page is displayed using the shaded pixels 1330. For each successive page, row and column shifts are used. Note that the variations discussed above for the row and column shifting can be applied to this technique as well. Also, further variations are possible such as shifting in a clockwise or counterclockwise circular pattern. In a clockwise pattern, for example, the image is shifted for each page from left to right, then from top to bottom, then from right to left, and finally from bottom to top to return to the original starting position. This can be illustrated by referring to Fig. 11, for example, and applying an x-y coordinate system where the upper left hand pixel has the coordinates (0,0), e.g., column=0 and row=0, the pixel to the right has the coordinates (1,0), e.g.,

column=1 and row=0, and the pixel below has the coordinates (0,1), e.g., column=0 and row=1. Then, by identifying the pixels that are used to display a page by the upper left-hand pixel coordinate, the clockwise circular pattern can be described by the series: (0,0), (1,0), (2,0), (2,1), (2,2), (1,2), (0,2), (0,1), (0,0). An analogous counterclockwise pattern can be described by the series: (0,0), (0,1), (0,2), (1,2), (2,2), (2,1), (2,0), (1,0), (0,0).

Furthermore, column based shifting may be used from left to right across the display screen 520 for a given row position. Then the row position can be incremented, and a further series of column-based shifts can occur. For the next row, the column position can be reset, or a zigzag pattern may be used by working in the reverse column order. For example, the pattern with a column reset can be described by the series: (0,0), (1,0), (2,0), (0,1), (1,1), (2,1), (0,2), (1,2), (2,2). The zigzag pattern can be described by the series: (0,0), (1,0), (2,0), (2,1), (1,1), (0,1), (0,2), (1,2), (2,2). Analogous right to left patterns may be used. When the final position is reached, e.g., position (2,2), the pattern can be followed in reverse, or by starting over from the original starting position. Similarly, row based shifting may be used from top to bottom across the display screen 520 for a given column position, with either a row reset or zigzag pattern. For example, the pattern with a row reset can be described by the series: (0,0), (0,1), (0,2), (1,0), (1,1), (1,2), (2,0), (2,1), (2,2). The zigzag pattern can be described by the series: (0,0), (0,1), (0,2), (1,2), (1,1), (1,0), (2,0), (2,1), (2,2). Analogous right to left patterns may be used. In another approach, a spiral pattern is used, for example, as described by the series: (0,0), (1,0), (2,0), (2,1), (2,2), (1,2), (0,2), (0,1), (1,1). Various other patterns may be used as well. Moreover, substantially random vertical and/or horizontal offsets may be selected for row and/or column shifting, e.g., by providing a random number generator that outputs an integer between the minimum and maximum offset values. The term "random" is meant to encompass "pseudo-random."

By shifting the starting row and/or column of each page relative to the previous page, image retention effects caused by repeated image/text updates and the subsequent imperfect erase or reset are significantly reduced, resulting in a higher quality image. In the examples provided, an active matrix E-ink type display is used as the screen of an electronic book. The display includes both source drivers, which supply the data to be displayed, and gate drivers, which switch the lines. With row shifting, for example,

during an image update, the image data are sent from the source drivers, and each row is switched using the row drivers, scanning from the top line of the display region to the bottom line. The nth page is updated starting from the first row of the display, while the (n+1)th page is updated with a vertical shift, e.g., starting from the second row of the display. The (n+2)th page may start from the third row. Or, if the maximum shift has been reached, e.g., two rows maximum, the third page starts from the first row, and the pattern continues. In this way, the probability that the same pixel is repeatedly switched to, e.g., black text, is significantly reduced, avoiding the integration of image retention on the pixels. It has been experimentally observed that the frequency of the forced reset of the whole display can be significantly reduced, thereby reducing power consumption and improving user convenience.

While there has been shown and described what are considered to be preferred embodiments of the invention, it will, of course, be understood that various modifications and changes in form or detail could readily be made without departing from the spirit of the invention. It is therefore intended that the invention not be limited to the exact forms described and illustrated, but should be construed to cover all modifications that may fall within the scope of the appended claims.